ATOMICS

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A bi-monthly journal devoted to the needs and interests of everybody concerned with the application of nuclear energy in all its various phases in industry, in the medical and biological sciences and in the development of electrical power and heat.

ATOMICS

ANDREW W. KRAMER, *Editor*

Exploded Belief . . . Few of us in America or in other Western democratic countries have ever doubted the inevitability of progress. Belief in progress has been one of the principle ingredients in our thinking since the time of the industrial revolution; continued progress is something we have just taken for granted. Yet, now, according to Michael Amrine, writing in the *New York Times Magazine,* this controlling assumption of Western Civilization has finally exploded in the atomic age.

Although a great many poets and philosophers have been saying gloomy things about progress with increasing insistence during the last fifty years, very few of us, at least in America, have taken their prognostications seriously. As Mr. Amrine points out, in America, our belief in progress, as expressed, for instance, in the happy ending, is particularly intense. In Britain men for centuries have felt that law and order would somehow "muddle through", and it has always been the thread of cohesion in European culture before and after Rousseau's phrase, "the infinite perfectibility of the human race." The era of happy faith in Man's reason may be discerned as having begun with Copernicus and ended with Einstein.

"Thirty years ago," writes Mr. Amrine, "Millikan, discussing the happy things to come out of the laboratory, put the question something like this: 'Who can doubt that the London cab driver of today is a far happier man than the ignorant London cabby of 100 years ago?' If Millikan were to ask that question in a community forum today, many ministers, social workers, and psychiatrists—and very likely a cab driver or two—would get up and say, 'I wonder.'

"There is a growing suspician that our grandfathers may not have lived so long as we do but lived better. They did not have automatic toasters, but they had better bread; they did not have television, but the shadow pictures that grandfather made with his hands by the light of the fire may have been more satisfying to his family. This is not facetious."

Speaking before a group of students several years before the atomic bomb, Dr. Einstein posed the question: "Why does this magnificent applied science, which saves work and makes life easier, bring us so little happiness?" It was a time when most Americans still thought

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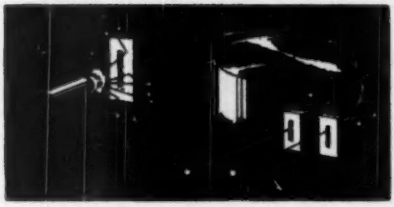
applied science was the main source of happiness. With his usual lucidity in these matters, Dr. Einstein answered his own question: "Because we have not yet learned how to make sensible use of it. It is not enough that you should understand about applied science in order that your work may increase man's blessings. Concern for the man himself and his fate must always form the chief interest of all technical endeavors. Never forget this in the midst of your diagrams and equations."

The basic belief of Western Man that his material progress was inevitable, and irreversible, Mr. Amrine points out was perhaps best expressed in the phrase still thrown at those who want to slow down our material civilization to keep pace with our social ability; "Ah, but you can't turn back the clock." As a matter of fact, nothing is easier than to turn back a clock, as the nearest 10-year-old child can show you. Our machines do what we tell them to do, and our whole civilization is no more secure than ourselves.

"The Nazis," concludes Mr. Amrine, "built better roads than the Romans, and German science once led the world. But they turned the clock of civilization back a thousand years.

"What we were slow to learn from Hitler we must be swift to learn from Hiroshima; it is a small world—or a large one—only as men are great and petty. Man is more than intelligence, civilization is more than knowledge."



NUCLEAR POWER ENGINEERING

Because of the space needed to present the newly released data on the low power reactors at Argonne and Los Alamos National Laboratories it became necessary, in this issue of ATOMICS, to omit the regular installment of the series "Nuclear Power Engineering." We were reluctant to do this but felt that the details of the reactors, about which there has been so much speculation, were of sufficient importance to our readers to present all the data in a single issue. Part XIII of the Nuclear Power Series will appear as usual in the next issue.

First Detailed Description of the AEC Research Reactors

Here, for the first time, we present a detailed description of the low-power nuclear reactors developed for research at the Argonne National Laboratory. Here, you will find all the answers to questions you have been wondering about since the release of the Smyth Report five years ago. You will find out how big the reactors are, exactly how large the carbon blocks were in the first atomic pile at the University of Chicago, how many layers there were. Also you will find details of the mechanical arrangement for controlling the operation of the piles, what materials were used, details of safety features, etc. For the first time also you will be given the exact cross section of thermal neutrons for fission, capture and scattering for the isotopes of uranium and for natural uranium. In fact, with the descriptions given, you would have little difficulty of making a neuclear reactor yourself, provided you could get hold of some 50 tons of uranium 6 or 7 tons of heavy water—and, last but not least, permission to use the fissionable material, from the Atomic Energy Commission. All this information has been officially released by the U. S. Atomic Energy Commission in accordance with an International Declassification Conference held in February 1950 at the British Atomic Research Establishment, at Harwell, England. At this meeting, the U. S., the United Kingdom and Canada agreed to the release of this information. British and Canadian reactors affected by the revised Declassification policy are Gleep, a uranium and graphite reactor located at Harwell, England, and Zeep, a uranium and heavy water reactor located at Chalk River, Ontario, Canada

On December 2, 1942, man achieved the first self-sustaining nuclear chain reaction and thereby initiated the controlled release of nuclear energy. The pile, a huge cube of graphite and uranium, had been constructed by a small group of physicists of the University of Chicago's Metallurgical Laboratory.

Constructed in a squash court of the University's Stagg Field, it was operated at a maximum power level of 200 watts since higher level operation of an unshielded reactor was deemed to emit radiation in quantities which conceivably might be injurious to the operating personnel.

The operation of the West Stands reactor was terminated on February 28, 1943, and the reactor was dismantled and moved to the Laboratory's Palos Park site where it was reconstructed and provided with a radiation

shield. The reconstruction was done on a very short time schedule since important information required for the design of plutonium-producing reactors to be constructed at Hanford (Washington) Works had to be procured. Only 21 days were required for the dismantling, moving, and reconstruction of the reactor, and on March 20, 1943 the Palos Park reactor, built of the same materials used at West Stands, began to function.

DESCRIPTION OF REACTOR

The rebuilt reactor looks very much like a large windowless, two-story square concrete building. Its external measurements are: 30 ft. wide, 32 ft. long, and 21 ft. high. A small laboratory has been constructed on top of the reactor in which experimental work can be performed using radiation generated within the pile. See Fig. 1.

Inside the 5-ft. concrete walls is the reactor core, a cube-shaped pile of graphite into which lumps of uranium have been imbedded according to a pre-determined lattice-type pattern. The top of the graphite-uranium pile is covered with 6-in. of lead and about 4 ft. of solid wood.

The small experimental laboratory is constructed atop of this shield.

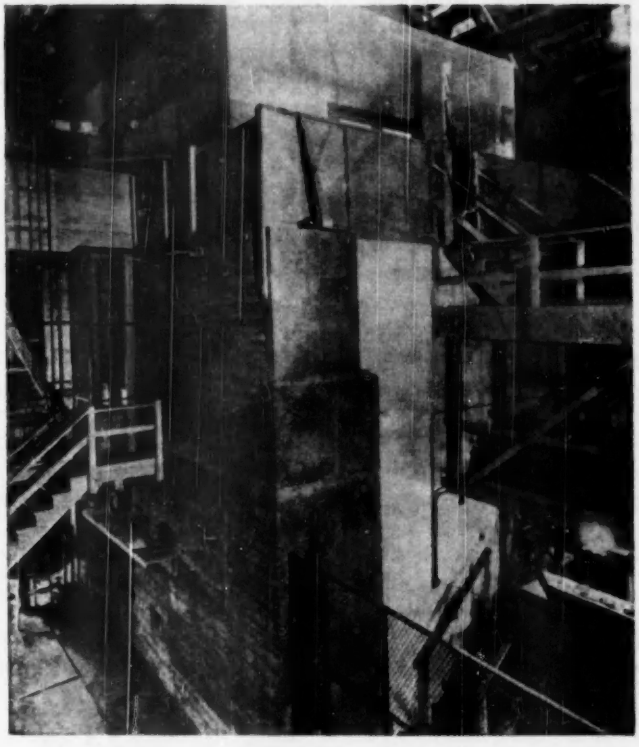


Fig. 1 View of the east (left side) and north faces of the Argonne National Laboratory's uranium-graphite nuclear reactor. The reactor was originally constructed at West Stands, Stagg Field, University of Chicago and operated for the first time on December 2, 1942. The reactor core is a huge cube (20 ft. wide, 22 ft. long and 21 ft. high) of graphite in which 52 tons of uranium and uranium oxide are imbedded in a lattice type arrangement. A 5-ft. thick concrete shield surrounds the core. A small laboratory is mounted on top.

Various controls and safety rods enter the sides of the reactor from supporting platforms built around the faces or sides of the reactor. Numerous openings are available in the front face of the reactor so that blocks of graphite, known as stringers, may be removed and test materials inserted into the active area of the reactor.

CONSTRUCTION

The concrete walls were first poured with the front and top open, leaving a vault in which the reactor proper could be built up, layer by layer, in a space 22 ft. long and 20 ft. wide. As in the West Stands reactor, the basic construction unit for the graphite-uranium reactor was a graphite block, 4⅛ in. by 4⅛ in. The length of the blocks varied but most of them were 16½ in. long.

Cylindrical recesses spaced 8¼ in. from center to center were cut in the blocks. Uranium cylinders 2¼ in. in diameter and weighing about 6 lbs. were inserted into these recesses. Blocks prepared in this manner are called "live" graphite. Other graphite blocks contained no uranium, but were used simply as spacing blocks. These are called "dead" graphite.

The graphite blocks were cut to length and the uranium bodies were placed into the recesses to provide live graphite rows spaced by rows of dead graphite blocks across the pile to form horizontal layers. Each horizontal uranium-bearing layer was spaced from the layer below by a horizontal dead graphite layer, thus a three dimensional lattice was formed. All of the blocks were closely piled so as to reduce air spaces.

In order to reflect stray neutrons back into the reactor core, the uranium-bearing material was surrounded on all sides by at least twelve inches of dead graphite. The reactor became chain reacting or critical at the 50th layer. An additional four layers of dead graphite were then added above the 50th layer to complete the reflector across the top of the reactor.

MATERIALS USED

Because of the relatively small amount of uranium metal available at the time of the construction of the reactor, a large number of the recesses were filled with uranium oxide. To use the available metal in the most efficient manner, it was placed in the center of the reactor and was surrounded with the uranium oxide lumps. Accordingly, live graphite pieces containing about ten tons of metal lumps were piled in layers to form a central lattice mass about 13 ft. wide, 10 ft. deep and 10 ft. high, which was positioned between the 16th and 48th layers of the reactor.

The reactor contains about 3200 uranium metal lumps weighing about ten tons. About 14,500 uranium oxide lumps were used, bringing the total amount of uranium in the reactor to about 50 tons. The weight of graphite in the reactor is about 472 tons and the total weight of the reactor including the core, reflector, shield, and lead top is in excess of 1400 tons.

CONTROL SYSTEM

As the reactor was being built, various slots or openings were provided for the control, shim, and safety rods. There are five control rods, a regulating rod and a shim rod on the north face of the reactor and three safety rods on the east face. These rods, 17 ft. long, are bronze strips covered with cadmium which is an excellent absorber of neutrons.

The control system is designed for manual regulation of the reactor, for automatic safety control, and for automatic manipulation of the regulating

rod in a manner such as to maintain constant intensity in the reactor. The safety rods are equipped with 100 lb. weights so that they are pulled into the reactor in the event of electrical power failure.

NEUTRON COLUMN

Extending above the 54th layer of graphite was a dead graphite pier to act as a thermal neutron column for slowing down the neutrons and making them available for research. This column is several feet square and is about 5 ft. high and passes through the center of the lead and wood top covering the reactor core. Some neutrons created inside the reactor pass through this column of graphite and, as a result of numerous collisions with carbon atoms, their speed is greatly reduced. The column is covered with a cadmium layer in which a small opening has been provided. Slow neutrons passing through this opening in a narrow beam are used by experimental physicists in numerous research activities.

The beam of neutrons coming from the thermal column may have a diameter as small as a lead pencil or as great as 5 ft., depending upon research needs. Even with the small opening, the number of neutrons involved is very large—some millions of neutrons per second. While the neutrons have been slowed down, they still travel at a terrific speed: 2000 meters per second, or approximately 4000 miles per hour. On the other hand, a fast neutron speeds along at roughly 10,000 times as fast.

INSTRUMENTATION

As the construction of the West Stands reactor proceeded, a series of

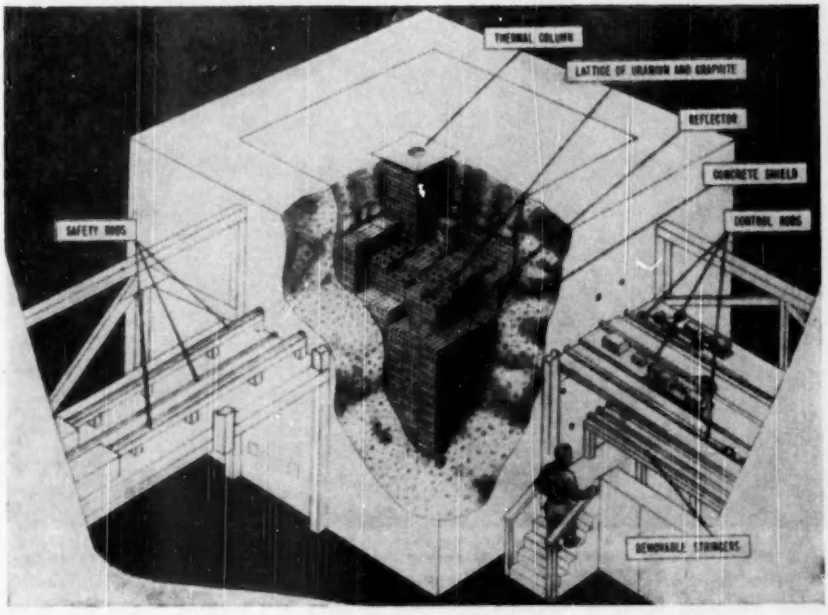


Fig. 2 Artist's sketch of the Argonne National Laboratory's graphite-moderated nuclear reactor. Control and safety rods enter the sides of the reactor from platforms. In order to reflect neutrons back into the reactor core, the uranium bearing section is surrounded by a graphite layer known as a reflector.

measurements was made to be sure that the critical dimensions were not reached inadvertently. These measurements served also to check the neutron multiplication properties of the structure during assembly, so that scientists could predict when the critical point would be reached. A similar procedure was followed in the subsequent rebuilding of the reactor.

In general, any detector of neutrons or gamma radiation can be used for measuring the intensity of the reaction. During the construction of the West Stands reactor, a 2 by 2 in. slot running from the north face of the pile to slightly beyond the center of the pile was built into the eleventh layer. A boron trifluoride proportional counter in a graphite block was

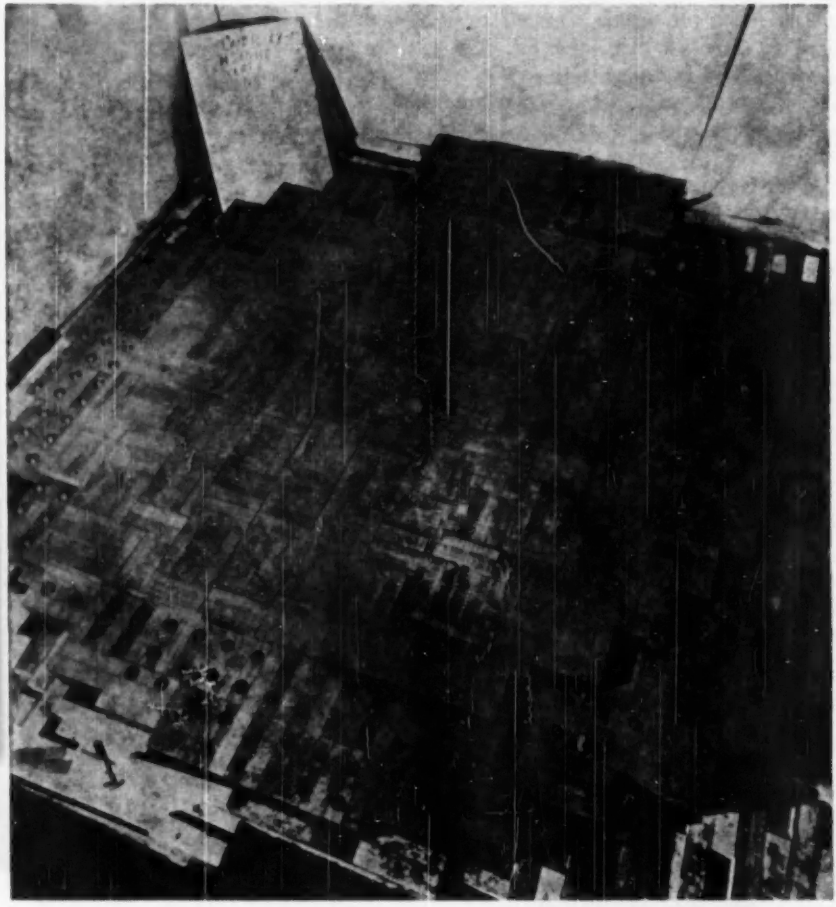


Fig. 3 This is the only photograph made during the construction of the first nuclear reactor. The photograph was made in November 1942 as the 19th layer of graphite was being added. Alternate layers of graphite contained uranium and uranium oxide and were spaced by layers of *dead* graphite. Layer 1, almost covered in this photograph, contained uranium. Actual construction was carried out in this manner to tthe 50th layer, which was about one layer beyond the critical or opening dimensions. The roughly spherical form of the structure is shown as is some of the supporting framework.

pushed along this slot to the center of the eleventh layer. The counting of neutrons was thus achieved and instruments, located outside the reactor, made a continuous record of the counting rate. To detect the radiation at the periphery of the rebuilt reactor, an ionization chamber was installed inside the concrete shield near the safety rods.

FISSION PROCESS

The principle of operation of a nuclear reactor is simple enough. If in a mass of uranium one neutron causes a fission to occur resulting in the formation of two or more neutrons, it is conceivable that the number of fissions may increase steadily with the consequent release of sizeable amounts of energy. However, there is a great competition for these neutrons and the question of whether a chain reaction does or does not take place in a given structure depends upon the result of a competition among four processes. These are:

(1) escape of the neutron to the outside.
(2) non-fission capture of the neutron by uranium.
(3) capture of the neutron by impurities in the construction materials.
(4) fission capture of the neutron by uranium.

It is obvious that a chain reaction will occur if the number of new neutrons, created by the fourth process, exceed the loss of neutrons due to the other three processes.

MODERATOR

The relative chance of fission capture as opposed to competing non-fission processes depends upon the speed at which the neutron travels. The chance for fission increases if the neutron is traveling slowly... Fast neutrons are slowed down in passing through materials of low atomic weight. The greatest loss of speed per collision would occur if the neutron and the atoms of the moderating material had identical weights. This condition cannot bet met in nature, but hydrogen, whose atoms weigh approximately the same as the neutron, is a good moderator and low-weight deuterium (heavy hydrogen), beryllium, and carbon are effective moderators.

While no one of these elements may be excluded from the list of possible moderating materials, it was decided West Stands reactor would be constructed with graphite, a form of carbon. Experiments have shown that high speed neutrons resulting from the fission process are practically all reduced to low speeds, suitable for fission capture, after passing through about eight to ten inches of graphite. It has been estimated that about 110 collisions with graphite atoms take place during this slowing down process.

NEUTRON CAPTURE BY IMPURITIES

Very careful purification of the uranium and of the moderator is necessary to reduce the number of cases of non-fission capture of neutrons by impurities. Calculations have shown that the maximum permissible amount of impurities are a few parts per million in the uranium or the moderating material. Not only was the amount of uranium available in 1942 and 1943 very limited, but both the uranium and graphite were of doubtful purity. It is to be noted that prior to 1940 the amount of uranium produced in this country was very limited and that graphite had never been produced in quantity with anything like the purity that was required of a moderator.

REPRODUCTION FACTOR K

The whole success or failure of the construction of the first nuclear reactor depended upon the reproduction factor k. Suppose that there is a given number of neutrons present in a graphite-uranium system at a given time. Some of these neutrons, under proper conditions will cause fissions to occur and thus new neutrons will be released. The ratio of the number of newly created neutrons to the number of original neutrons is known as the reproduction factor k. Thus, if 100 neutrons cause the production of 105 neutrons, factor k is 1.05. If this number is greater than 1, the chain reaction is assured. If k is less than 1, the chain reaction could not exist because the neutron population would steadily decrease.[1]

THE ARGONNE HEAVY WATER REACTOR

HISTORY

Because there was always the remote chance that graphite moderated nuclear reactors could not produce the fissionable material required for the program of the Manhattan Project, much thought was given in 1943 to the construction of a heavy water moderated reactor. In consequence, the production of heavy water in sizeable quantities was undertaken (at other locations) early in the development of the atomic energy program. Measurements performed on heavy water with the use of the graphite moderated pile during the summer of 1943 proved the feasibility of a heavy water reactor and had produced sufficient information to permit its construction.

Construction of a building was begun in September, 1943 and on May 15, 1944 the heavy water reactor was operated at low power. Thus, it became the world's first heavy water nuclear pile.

DESCRIPTION OF HEAVY WATER REACTOR

In comparison with graphite moderated reactors, the heavy water reactor is quite small. It consists of an aluminum tank, 6 ft. in diameter and 8 ft., 10 in. high, which is filled with approximately 6½ tons of heavy water (amount contained in 32,000 tons of ordinary water) and into which are suspended 120 uranium metal rods, 1.1 in. in diameter and 6 ft. long. The uranium rods, whose total weight is nearly three tons, are arranged to form a square lattice with the distance from center to center being 5⅜ in. Heavy water, which is present in ordinary water as one part in 5000, serves to slow down the speed of the neutrons in the same manner and for the same reason as is accomplished by graphite in the other reactor. Heavy water is more effective than graphite in slowing down neutrons and does not absorb neutrons as readily as does graphite. To remove the heat created in the fission process, the heavy water is circulated through a heat exchanger. Thus, the heavy water serves not only as a moderator, but as a cooling agents as well.

The reactor tank rests on a 2-ft. layer of graphite blocks supported by the concrete pile foundation. The graphite reflects the neutrons to the reactor core. In addition to this neutron reflector on the bottom, the sides are provided with a reflector of equal thickness.

A 4-in. shield of lead-cadmium alloy surrounds the reflector and fits snugly against a thick concrete shield which encases the entire reactor. The

[1] Further data on nuclear fission is given at the end of this article.

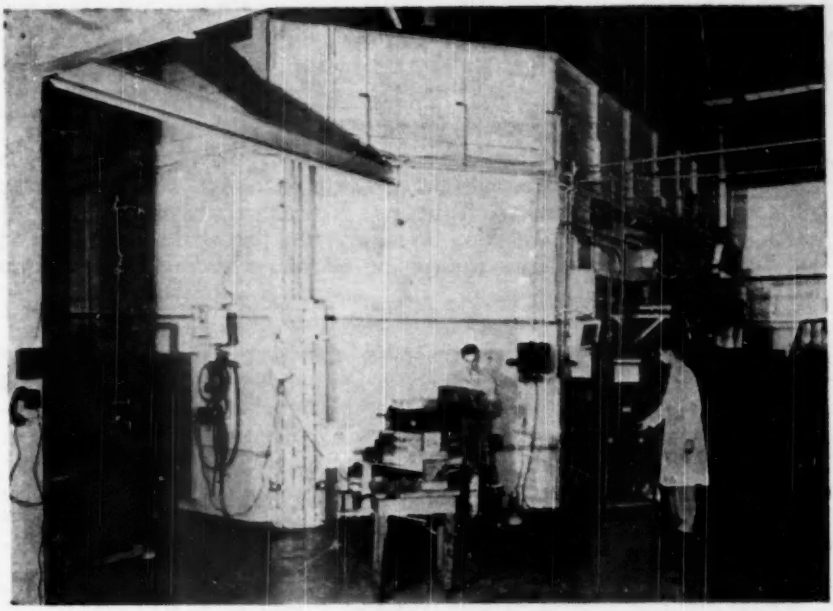


Fig. 4 General view of the Argonne heavy water moderated nuclear reactor. The reactor core consists of a tank of heavy water in which uranium rods are suspended. To reflect neutrons back into the uranium section a two feet thick wall of graphite surrounds the reactor core. An 8-ft. thick concrete shield surrounds the entire assembly.

lead-cadmium alloy protects the concrete from exposure to neutron and gamma radiation. A 1-ft. shield of lead bricks is placed on top of the graphite reflector and is continued over the top plate of the reactor tank. Between the bottom of the lead cover and the top plate of the reactor tank is a thin layer of cadmium metal.

Neutrons escaping from the uranium section of the reactor are slowed down by collisions with atoms in the heavy water and are then absorbed by the cadmium shield. This absorption of neutrons causes the cadmium to emit gamma rays which are in turn stopped by the lead shield. (The capture of a neutron by any material immediately results in the formation and emission of a gamma ray). Thus, personnel during the loading and unloading of fuel are protected from neutrons by the cadmium and from gamma rays by the lead. The thick lead shield at the side and bottom contains copper tubing for circulating cooling water to remove the heat generated in the shield and in the graphite.

The space between the heavy water and the cover of the tank is filled with helium. This inert gas replaces ordinary air which would normally be present and which must be kept out of the system. Moisture, in the air, would be condensed inside the reactor tank and would dilute the rare and expensive heavy water. There is another objection to the use of air. Inasmuch as nitrogen makes up about four-fifths of the atmosphere, radiation bombardment of air would result in the formation of nitric acid.

Two blower pumps circulate the helium through a cooler and through a catalyst chamber. These pumps, one of which is normally a stand-by pump,

circulates the helium gas and dissociated heavy water. Under neutron bombardment heavy water molecules break apart to form oxygen and heavy hydrogen and these gases are recombined in the catalytic chamber and returned to the reactor tank.

CONCRETE BIOLOGICAL SHIELD

The reactor core is surrounded with a biological shield which is in the form of an approximately octagonal concrete prism 13 ft. high and having walls 8 ft. thick. The top of the reactor is shielded with a 4-ft. layer of blocks of wood and steel weighing 80 tons. Only five of the eight faces of the reactor are visible because the cooling machinery room encloses within itself three of the faces.

EXPERIMENTAL OPENINGS

Eleven openings, closed by removable shielding plugs, penetrate the biological shield and the graphite reflector to provide facilities for measuring the neutron intensity of the reactor, for exposing materials to neutrons, and for permitting the passage of beams of radiation from the reactor. Four of these openings contain ion chambers (neutron detection instruments) used in operating the reactor. The other seven may be opened to permit the passage of beams of neutrons or may be used to introduce materials into the reflector near the reactor tank for making them radioactive by exposure to neutrons.

On the east face of the reactor is a large opening (roughly 30 in. square) also used for irradiating materials by neutron exposure. The opening contains twenty hollow graphite stringers to hold materials to be irradiated.

NEUTRON COLUMN

A thermal neutron column carries a beam of slow neutrons from the reactor. The column consists of a stack of ordinary graphite blocks 5 ft. square and 7 ft. 8 in. long extending back to the neutron reflector. The end extending through the concrete shield is covered with a cadmium curtain and a 2-ft. lead and iron shield in which an 8-in. square opening is provided. Neutrons created in the reactor are slowed down, to be in equilibrium with the room-temperature or thermal agitation of the graphite molecules, by repeated collisions with graphite atoms. When needed in research experiments, they leave the reactor through this opening. The size of the opening may be altered by changing the size of the cadmium cover.

RABBIT

In many experiments, materials made radioactive in the reactor must be removed from the reactor in a short time. To speed their insertion into and removal from the reactor, materials which lose their radioactivity after a few seconds travel in a pneumatic tube arrangement called the rabbit, built into one of the eleven openings passing through the concrete shield. Materials to be irradiated are placed in small plastic cylinders and are shot in and out of the reactor. Helium gas, which does not absorb neutrons and become radioactive, furnishes the push which speeds the samples in and out of the reactor.

CENTRAL EXPERIMENTAL THIMBLE

In addition to the eleven openings in the sides of the reactor described above, an opening known as the central experimental thimble extends from the top of the reactor into the heavy water. This opening has been made by extending a 4-in. aluminum pipe from the center of the top shield,

through the tank lid, and down to within a foot of the tank bottom through which various samples may be lowered into the center of the reactor for exposure to fast and slow neutrons. Thirty-two irradiations may be performed simultaneously by the use of this facility.

CONTROL SYSTEM

The Argonne heavy water reactor is equipped with two control rods, two safety rods, and three shim rods. All contain cadmium metal so that they will absorb neutrons and stop the chain reaction.

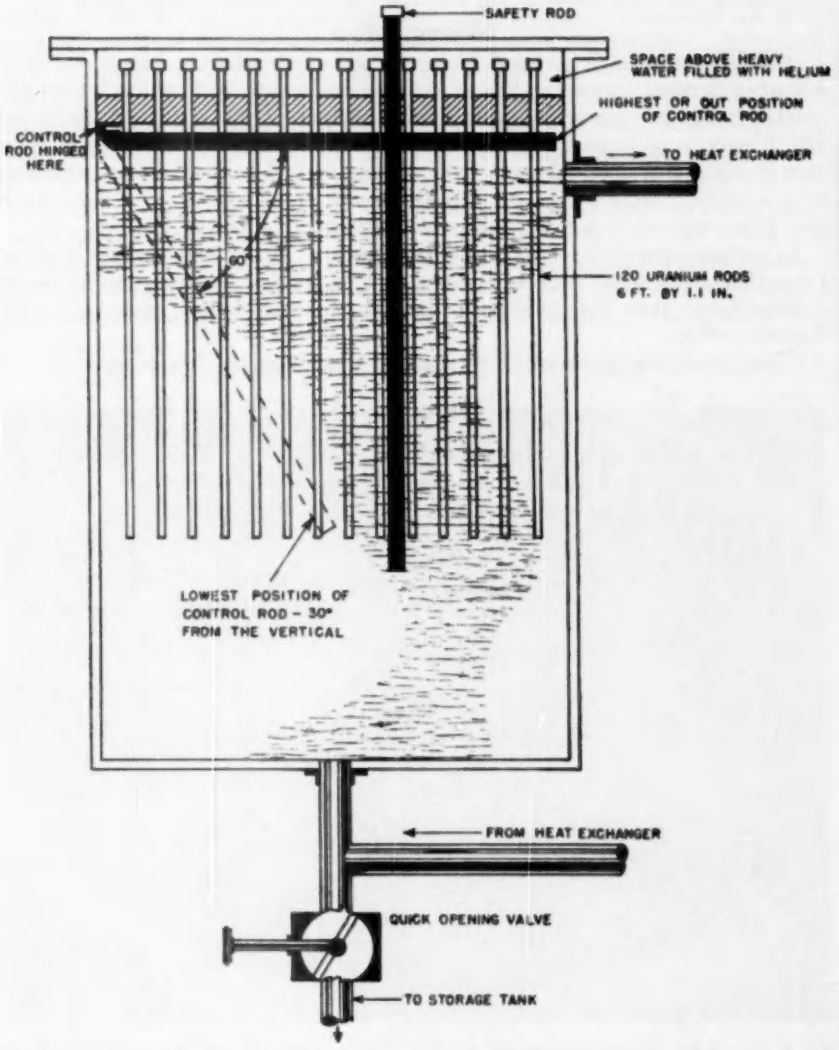

SAFETY ROD
SPACE ABOVE HEAVY WATER FILLED WITH HELIUM
HIGHEST OR OUT POSITION OF CONTROL ROD
CONTROL ROD HINGED HERE
TO HEAT EXCHANGER
60°
120 URANIUM RODS 6 FT. BY 1.1 IN.
LOWEST POSITION OF CONTROL ROD – 30° FROM THE VERTICAL
FROM HEAT EXCHANGER
QUICK OPENING VALVE
TO STORAGE TANK

Fig. 5 Diagram of the Argonne heavy water reactor showing arrangement of control and safety rods and heavy water circulating system. (This diagram was drawn from the description released by AEC)

The safety and control rods are each formed of a 3½-in. tubular sandwich of 1/32-in. cadmium placed between two aluminum tubes. These rods are hinged to the bottom side of the cover of the heavy water tank. When they are in the "in" position (reactor would not be operating), they are hanging about 30 deg. from a vertical position. When the rods are in the "out" position, the are suspended in an almost horizontal position above the water in the tank. These rods move through a sixty deg. arc.

The shim rods, sometimes called auxiliary control rods, are contained in aluminum tubes and are mounted inside the tank in a vertical position with one end of the rods penetrating through the top of the reactor tank.

COOLING SYSTEM

The heavy water is pumped from the top of the reactor, passed through a heat exchanger located in the adjacent pump room, and fed back into the reactor tank through an opening at the bottom of the tank. In this way, 300 kilowatts of heat is removed from the reactor. The heavy water flow rate is 200 gpm. Experiments have shown that this rate of flow produces only a minor ripple in the surface of the water and experience has shown that this ripple does not introduce any instability into the reactor.

In normal operation, the average temperature of the heavy water flowing from the tank to the heat exchanger is 95 F while the heavy water being re-introduced into the reactor is, on the average, about seven or eight degrees cooler.

The heat exchanger permits the heat to flow from the heavy water to the

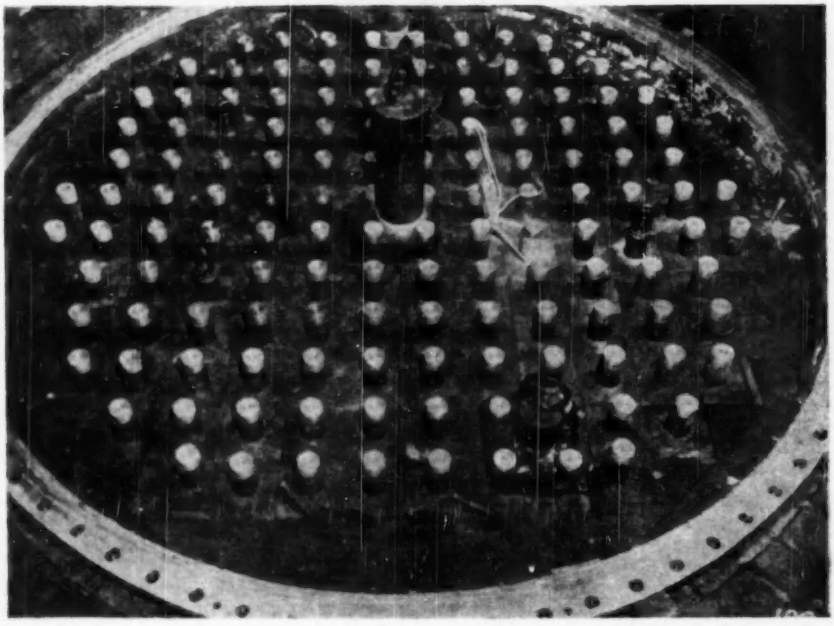


Fig. 6 Top of the reactor core of the Argonne heavy water reactor. The shield has been removed to show the ends of the uranium rods which are suspended in a tank of heavy water. The large object in the center is the thimble which extends nearly to the bottom of the tank. Materials to be made radioactive are lowered into this hole.

cooling water, but does not permit the flow of heavy water into the light water. There is a certain amount of radioactivity associated with the heavy water, but there is no way for this activity to be transmitted to the cooling water. Should a leak occur, radioactive heavy water might enter the light water cooling system, but Geiger counters inserted in the cooling line would immediately reveal the presence of radioactivity and necessary steps to prevent further loss of the valuable heavy water would be taken.

OPERATION OF THE REACTOR

The controls for operating the reactor are located in a room near the reactor's north face. Here, an operator may measure and control all of the major aspects of the reactor's operation. To start the reactor, the operator merely pushes a button and the 32 lb. safety rods are pulled out of the reactor. By pressing another push button, one of the two motor-driven control rods is removed. To shut off the reactor, the operator causes the safety rods to fall back into vertical positions inside the tank. If the power of the reactor should become too great, if some of the controls should fail to function, or if there should be an interruption in the electrical power supply, the safety rods would automatically fall into the "in" position by gravity and the reactor would shut down immediately. As a further measure to cause a sudden stop in the operation of the reactor, a properly located large quick-opening valve can discharge the moderator by gravity to a storage tank.

The shim rods are usually not moved but are allowed to remain fairly constant in day to day operation. Occasionally, however, they are adjusted when materials are irradiated in the reactor. For example, if a material possessing great ability to capture neutrons is placed into the reactor for irradiation, the shim rods will be withdrawn to reduce the amount of neutron capture by the cadmium in the shim rods, thus making more neutrons available for capture by the newly-introduced sample. Conversely, in some instances, the rods would be lowered deeper into the water so as to increase the number of neutrons being captured.

BACKGROUND INFORMATION ON THE LOS ALAMOS WATER BOILER

Plans for the Water Boiler, a homogeneous chain reactor using as fuel an enriched uranyl salt solution in water, were started in August 1943 at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

Preliminary calculations for the proposed reactor were carried through by R. F. Christy and the design for the first model (LOPO) was completed and developed by a group of research workers under the direction of D. W. Kerst. A second high-power model (HYPO) was later designed and built under the leadership of L. D. P. King with the advice of E. Fermi and the chemical work was done under the direction of L. Helmholtz.

Basically, the Water Boiler, as developed up to January 1950, consisted of a container filled with an enriched uranyl solution surrounded by a neutron and necessary radiation shielding, with the necessary control rods to regulate the power level and a cooling system to carry off heat generated by the reaction.

LOW-POWER REACTOR

The original water boiler design for a low-power reactor (LOPO) was

completed in November 1943. It was decided to build this device before attempting the later model reactor of higher power. In the low-power unit the shielding and cooling problems were eliminated. At the same time its operation would indicate to what extent gases might be evolved from fission fragments and decomposition of the water and would reveal unforeseen difficulties in keeping the salt solution critical.

A separate building for LOPO was erected at a location remote from the main portion of the technical area at Los Alamos. Assembly proceeded through the spring of 1944 and the system became critical in May 1944 with 1.2 pounds of U-235. The highest power to which LOPO was run during its several months existence was about 50 milliwatts, which raised the temperature to about 94 F.

Members of the LOPO research group recall an incident involving Dr. Christy, who performed the theoretical studies and calculations which indicated that a water boiler reactor was feasible. As the reactor passed from the drawing boards to construction Dr. Christy became more and

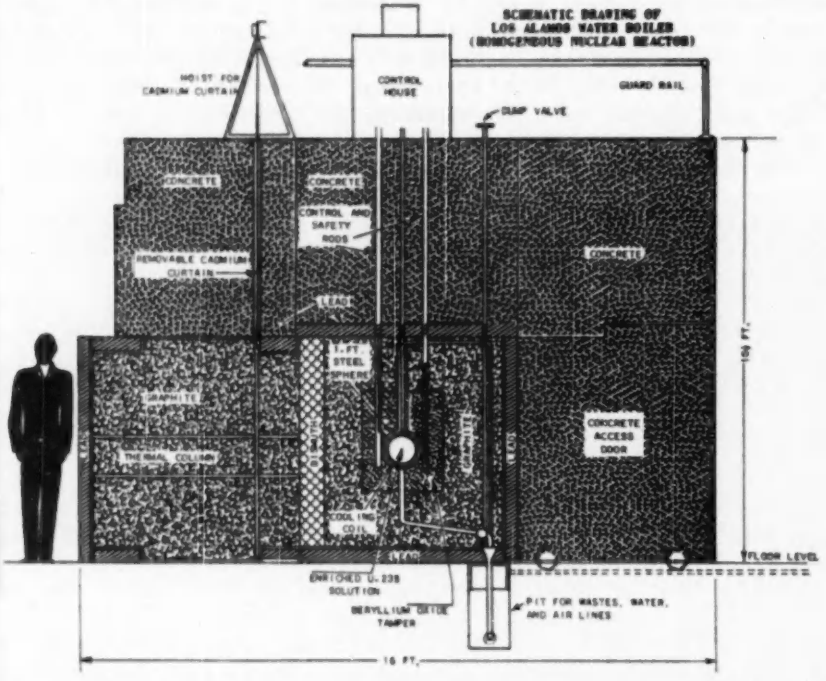


Fig. 7 Simplified drawing of the Los Alamos homogeneous reactor (water boiler) showing the arrangement of the small spherical reactor surrounded by tampers and shielding. The reactor fuel consists of a solution of uranium salt enriched in uranium 235. The inner tamper consists of a block of beryllium oxide surrounded by a larger graphite tamper. The shielding consists of a thin cadmium sheet to absorb slow neutrons, heavy concrete to slow down and absorb fast neutrons, and lead to absorb high-energy gamma radiation. At the front of the pile, here shown on the left, a graphite-filled tunnel or thermal column extends through the shielding. Note that the control rods do not extend into the reactor itself but into the beryllium oxide tamper. When completely inserted, the rods absorb enough neutrons to prevent the reaction from going.

more convinced that the theory was correct and that his estimates of the amount of fissionable material required and of the correct setting for the control rods were exact.

Despite this confidence on the part of the designer, the reactor was started cautiously with careful adjustment of control rods and gradual filling of the fuel container. However, when the critical point was eventually reached, Dr. Christy was proved correct. Both the amount of fuel and the control rod settings were *exactly as he had foretold.*

In view of the successful operation of LOPO, it seemed desirable to construct the high-power unit which would provide a more intense neutron source.

HIGH-POWER REACTOR

HYPO went critical in December 1944 with about 1.8 pounds of U-235, although the normal loading contains about 1.9 pounds of U-235. Except for minor design changes, HYPO, as originally constructed, has operated successfully for several years.

The Los Alamos Water Boiler has been used primarily for physical experiments requiring a concentrated neutron source. It is the smallest and most economical type of chain reactor so far built. The peak power of HYPO was about 6 kilowatts, representing a neutron flux of about 300 billion neutrons per square centimeter per second at the center of the reactor. A slow or thermal neutron flux of the order of a billion neutrons per square centimeter per second is available for research purposes in the graphite tamper surrounding the reactor.

The heart of the reactor consists of a 1-ft. spherical stainless steel container filled with a uranyl nitrate solution in water, known to the Los Alamos scientists as "Soup." The uranium in the uranyl salt contains about 1 part of fissionable U-235 isotope to 6 parts of non-fissionable U-238 compared to ordinary uranium which contains 1 part U-235 to 140 parts of U-238.

Surrounding the container is a reflector, or tamper, consisting of an inner core of beryllium oxide supplemented by a shell of graphite. The reactor and tamper occupy a cube about 5 ft. on a side. A considerable amount of shielding is also necessary to protect operating personnel. The shield around the entire assembly consists of 4 in. of lead, 1/32 in. of cadmium, and 5 ft. of poured concrete.

At the front or working face of the reactor a square tunnel pierces the shield. This tunnel was plugged with graphite to form a graphite thermal column and a number of ports for experimental irradiations were placed in the column and the tamper. A one-inch tube also extends through the shield, tamper and through the reactor sphere itself. Los Alamos workers call this the "Glory Hole." It permits materials to be irradiated at the highest neutron flux level.

Because of its low-power, LOPO required no cooling system. In HYPO, however, a six-turn cooling coil of ½-in. tubing and having an effective length of 157 in. is wound in the form of a helix inside the sphere. About 50 gallons of water per hour is pumped through the cooling system, which is sufficient to permit year-round operation at six kilowatts. After passing through the reactor the cooling water is retained for a short time in a tank within the shielding to permit short-lived induced radioactivity to die down before it is released.

When operating, the water in the fuel solution is decomposed by the highly ionized fission products forming about one-half cubic foot of hydrogen and oxygen gas per hour. Since this chemical mixture is extremely explosive and also since highly radioactive gases are produced in fission, some means of diluting and flushing out these gases was required. This was accomplished by means of a double inlet-outlet tube welded to the top of the sphere. Air is pumped through the inner ¼-in. tube and is exhausted through the outer ¾-in. tube. The inner tube may be raised or lowered so that it acts as an indicator of the solution level. Also by leading the gas from the outlet tube through test equipment, rapid analysis of the boiler gas may be made.

Copper-constantin thermocouples for measuring temperatures are placed in a tube extending into the center of the sphere and are also connected to the water inlet and outlet tubes.

HYPO is controlled by means of a cadmium shim rod, two cadmium control rods, and a cadmium safety rod. The latter always remains out during operation, since it is used only to stop the chain reaction in case the intensity should get too high. For additional safety, the two control rods are designed with a release mechanism so that they can stop as well as control the reaction. If both control rods and the safety rod are dropped at the same time, the neutron intensity falls 85 percent within one second.

Under normal operating conditions the Water Boiler is self-regulating due to the temperature effect. As the temperature increases the volume of the solution expands and the reactivity per unit volume declines. This automatically slows down the reaction so that under normal conditions it is impossible for the reactor to get out of control. If the control rods are

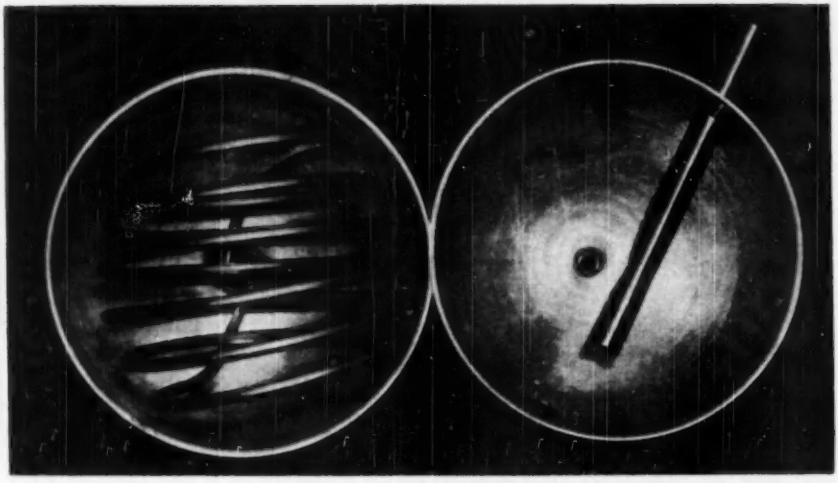


Fig. 8 Spherical container to hold enriched uranium fuel solution for the Los Alamos homogeneous reactor. The two halves of the sphere are made of stainless steel, one foot in diameter. Also shown, is the 6-turn stainless steel cooling coil through which water is circulated to carry off the heat generated in the reaction. The one-inch tube, called the "glory hole" will be welded horizontally through the sphere to permit materials to be placed in the region of the highest neutron flux. Pipes are welded to the holes in the top and bottom of the sphere to permit the fuel solution to be charged.

pulled out too rapidly, however, the heat release could possibly be non-uniform through the solution. For very short times, say 1/50 second or so, local hot spots might arise in which the solution would vaporize before the increased temperature had time to control the activity. In such cases the control rods would drop automatically to stop the reaction before serious damage to the reactor could occur.

The neutron flux is measured continuously by means of an ionization chamber, coated with uranium 235. The U-235 atoms in the coating undergo fission when hit by neutrons and the highly charged or ionized fission products can be detected by the chamber. The detection circuit leads into a very sensitive galvanometer in which the amount of electric current registered is proportional to the neutron flux. Independent U-235 chambers are used to trigger the safety and shim rods, which drop whenever a predetermined intensity is reached.

Extremely accurate control of the Water Boiler requires almost continuous adjustment of the control rods. This can be done by hand, but the job is tedious over long periods and so an automatic pilot has been designed to maintain the power at any fixed level.

OPERATION

All operations necessary to starting, running, and stopping HYPO are done from the control desk located in a room adjacent to that containing the reactor. Indicator lights and various warning signals aid the operator in controlling the reactor and locating difficulties.

The typical operating procedure for HYPO is as follows: Readings are made and recorded of the U-235 ionization chamber power indicator, solution level and sphere temperature. The flushing air and cooling water are turned on, and the direct-reading galvanometer is set on maximum sensitivity. The control rods are checked for "IN" position. The safety rod is raised, and the first control rod slowly raised while the galvanometer deflection is observed. After the first control rod is at the "OUT" position, the second rod is raised until the desired operating level is reached on the galvanometer. The automatic pilot can then be switched on to maintain constant power.

The reactor responds very rapidly to change in the control rod position, and this may be changed as rapidly as the operator desires. An experienced operator can bring HYPO up to full power in a few seconds.

With an inlet water temperature of about 45 F and 1.9 lbs. of U-235 in the boiler, HYPO could run continuously at 5.5 kw without exceeding a solution temperature of 185 F. if this should ever become necessary. At this power level, some excess reactivity is available for experiments on materials which absorb neutrons.

After reaching a constant operating temperature corresponding to a power level of one kilowatt or more the reactor will maintain an operating level constant to within a few tenths of one percent or better.

At Los Alamos a small chemical laboratory was erected near the HYPO site to recycle the fuel solution and to remove fission gragments. An underground stainless steel conduit was installed to carry the soup from the reactor to the chemical apparatus.

Since the successful operation of HYPO, the Water Boiler has been modified and improved in a number of ways to provide more efficient

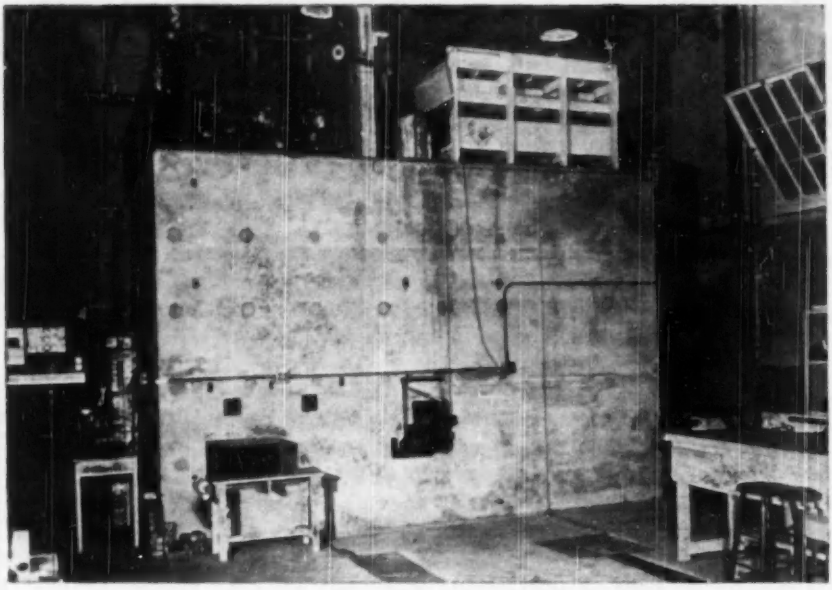


Fig. 9 View along the right hand face of the Los Alamos homogeneous reactor (water boiler) showing the concrete shielding which surrounds the reactor on all sides except the front. The ports in the concrete permit experiments in which various types of material may be placed in the intense neutron flux inside the shielding. A graphite filled tunnel extends through the shielding at the front. See diagram, Fig. 7.

operation at higher powers. The details of these later improvements have not yet been declassified.

Members of the research groups responsible for design, assembly and operation of the two Los Alamos Water Boilers are listed below:

Research Group for LOPO

D. W. Kerst, group leader; R. F. Christy, advisor; C. P. Baker, F. L. Bentzen, J. Bridge, R. E. Carter, H. Daghlian, G. Friedlander, H. Hammel, J. Hinton, F. de Hoffman, M. G. Holloway, L. D. P. King, H. M. Lehr, J. H. Midney, R. E. Schreiber, J. W. Starner and P. H. Watkins.

Research Group for HYPO

L. D. P. King, group leader; E. Fermi, advisor; H. L. Anderson, F. L. Bentzen, J. Bridge, R. E. CCarter, L. Helmholtz, J. Hinton, D. Nagal, J. C. Nevenzel, R. E. Schreiber, J. W. Starner, J. Tabin, and P. H. Watkins.

The names of the scientists working with the current or super-version of the Water Boiler are: L. D. P. King, group leader; M. E. Bunker, R. E. Carter, J. E. Evans, J. R. Phillips, J. W. Starner, W. E. Stein, B. E. Watt. The Chemistry Group consists of P. R. Hammond, in charge, H. M. Busey, A. S. Gurney, J. A. Leary, J. W. Schulte and W. R. Wykoff.

NUCLEAR DATA FOR LOW-POWER RESEARCH REACTORS

1. Thermal neutron cross sections for uranium

The following are currently accepted values in barns for an approximately Maxellian neutron spectrum with a most probable neutron velocity of 2200 meters per second:

Thermal neutron cross section for	U-235	U-238	Natural U
Fission	545	0	3.9
Capture	100	2.6	3.3
Scattering	8.2	8.2	8.2

2. Natural uranium fission cross section between 0.7 Mev and 5.0 Mev

The cross section for fission of natural uranium by neutrons having energies between 0.7 Mev and 5.0 Mev is given in Fig. 10. The curve has been drawn to fit the most reliable current experimental data.

3. Neutrons per thermal neutron fission

$$n = 2.5 \pm 0.1 \text{ for U-235}$$

4. Prompt neutron energy spectrum

The energy distribution of prompt neutrons resulting from the thermal neutron fission of U-235 is given by the formula:

$$\left[\sinh \sqrt{2E}\right] .\exp(-E)$$

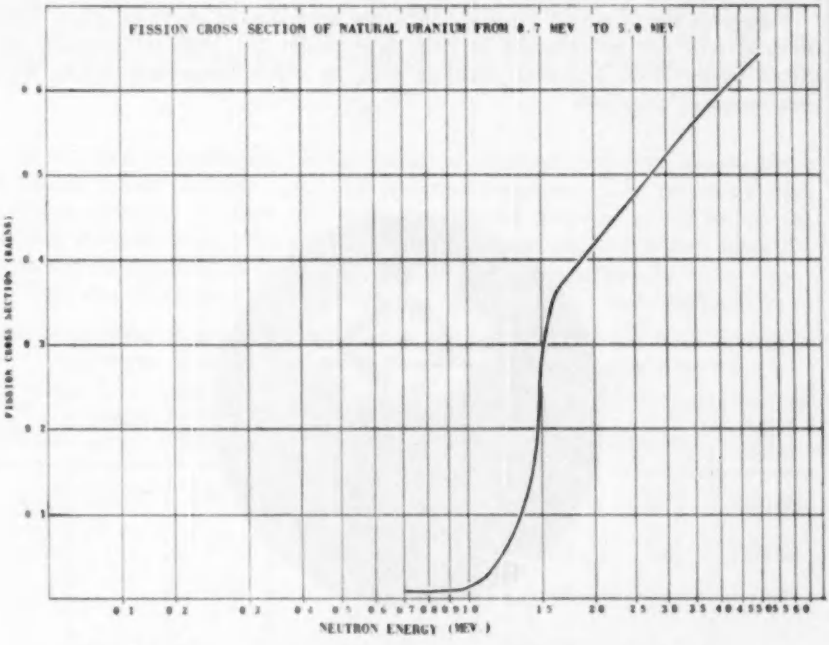


Fig. 10 Fission cross section of natural uranium from 0.7 MEV to 5.0 MEV

where E is the neutron energy in Mev in the laboratory system. This distribution function represents experimental data up to neutron energies of 13 Mev with a maximum deviation of 15%.

5. Fast fission effect

The following are typical values of the fast fission contribution to the reactivity of research reactors:

a. In a reactor of the "CP-2" or "GLEEP" type: 2.9%
b. In a reactor of the "CP-3" or "ZEEP" type: 3.1%

Note: "CP-2" and "GLEEP" are low-power graphite, uranium reactors at the Argonne National Laboratory and Harwell, respectively.
"CP-3" and "ZEEP" are low-power heavy water, uranium reactors at Argonne and Chalk River, respectively.

6. Resonance absorption integral

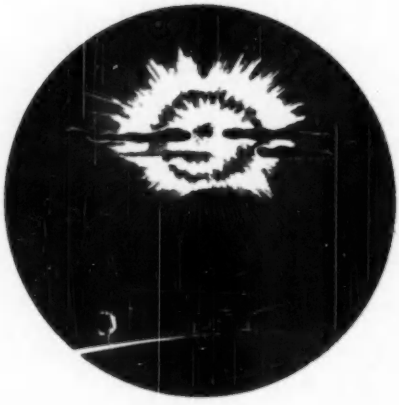
An approximate empirical formula for the effective value of the resonance absorption integral in natural uranium is

$$\int \sigma c\ (E)\ (dE/E) = 9.25 \quad [1 + 2.67\ (S/M)]$$

where the value is in barns, the integral is over the range of neutron energy from fission energy to thermal energy, and where S is the uranium surface area in cm^2 and M is the uranium mass in grams.

It is hoped that during later declassification actions appropriate credit may be given to the large number of individuals in the U.S., U.K. and Canada who have contributed to knowledge of the above nuclear data.

Values of the neutron cross sections for uranium at energies other than thermal will not be released at this time except for that information released under item 2 above. Similar data on other fissionable nuclei will also remain "classified."



Production of Atomic Energy By Nuclear Reactions

A general review of the present state of development of nuclear energy. In this short article, Dr. Wessel begins with a description of the atom in the light of modern physics and traces the development of nuclear energy from the early work of Rutherford to the practical attainment of nuclear fission. The most fundamental reactions are presented in detail. Dr. Wessel was formerly lecturer at the Technical College of Wigan and is the author of Physik published in 1938 in Germany. At present Professor resides in London, England

By DR. PAUL WESSEL

ACCORDING to modern nuclear physics, the nuclei of the atoms of all elements are built up of neutrons and protons. Within the framework of the nucleus, both particles possess (almost) exactly the same mass, to which is allotted, as the *atomic weight*, the number 1. The neutron (n_0^1) represents an electrical neutral particle, that is, with zero charge. The proton (H_1^1) which is nothing else than the nucleus of the hydrogen atom, has a positive electric charge of 1.

The chemical nature of an element is determined by the number of protons contained in the nucleus. This *atomic number*, Z also determines the place occupied by the element in the periodic table. Further the sum of the number of protons and neutrons establishes the atomic weight, A.

$$\text{Thus,} \quad A = \underset{H_1^1}{Z} + \underset{n_0^1}{Z}$$

Only a few elements are *simple* elements constituted by only single kinds of atoms. Most elements represent *complex* elements. The atoms of such complex elements all have the same number of protons but differ in the number of neutrons. Thus these atoms, which are called *isotopes*, have the same atomic number, Z but have different atomic weights, A.

Now, a neutron may be regarded as a proton which has combined with

Table showing the exact atomic weights of all the isotopes of the first three elements in the Periodic Classification, based on the atomic weight of oxygen, A = O^{16}

(NUCLEUS)	ATOMIC WEIGHT	(NUCLEUS)	ATOMIC WEIGHT	(NUCLEUS)	ATOMIC WEIGHT	(NUCLEUS)	ATOMIC WEIGHT
n_0^1	1.0090	H_1^1	1.0081	He_2^3	3.0171	Li_3^6	6.0169
		H_2^1	2.0147	He_2^4	4.0039	Li_3^7	7.0182
		H_1^3	3.0170	He_2^5	5.0137	Li_3^8	8.0251
				He_2^6	6.0208		

an electron. Symbolically we can express this as $n_0^1 = H_1^1 + e_{-1}^0$ where e_{-1}^0 represents the negative electron or *negatron* as it is sometimes called.

Therefore if an element of atomic number Z should by some process emit an electron, it means that a neutron has changed into a proton, and the element evidently experiences a transmutation into the nucleus E_{Z+1}^{A} of

Fig. 1 The isotopes of hydrogen. Left, the proton. Center, the deuteron. Right, the triton

the atom of a new element of atomic number $Z + 1$ and atomic weight A. The emmission of neutron, however, would create only a new isotope E_Z^{A-1} of the same element E of atomic number Z yet of atomic weight $A - 1$.

The simplest of all elements, hydrogen, (H) of the

atomic number	$Z = 1$, is a mixture of the
number	$i = 3$ isotopes, to which are
allotted the atomic weight	$A =$ 1and 2 and 3 respectively

(See Fig. 1, also Table I)

The element next following hydrogen in the periodic table is helium (He) of the

atomic number	$Z = 2$ having the
number	$i = 4$ isotopes of
atomic weights	$A = 3$ and 4 and further 5 and 6.

In the same way, the third element, lithium, has 3 isotopes. And, so on through the periodic classification until we come to the last of all natural elements, uranium (U) of

atomic number	$Z = 92$ having the
number	$i = 3$ isotopes of
atomic weights	$A = 234$, 235, 2nd 238 respectively.

Nuclear reactions reveal the nuclei as reservoirs of vast amounts of energy. This energy release is due to the fact that the sum of the masses in the initial state of the nuclear process is greater than the sum of the masses at its final state. The theory of Relativity declares by the equation, $E = mc^2$, where c is the velocity of light (3×10^{10} cm per sec) that a mass of the amount m is always equivalent to any kind of energy of the amount E.

Therefore, the comon atom of hydrogen, which has a mass 1/16 that of the oxygen atom ($0 = 26.571 \times 10^{-24}$ gram) it follows from the equation $1/16 \times 26.571^{-24} \times (3 \times 10^{10})^2$ that one mass unit (1/16th the weight

Fig. 2 The isotopes of helium. He^3, He^4, He^5, and He^6 respectively. All have the same Z, ie, atomic number, or number of protons, 2. The number of neutrons varies from 1 in the case of He^3 to 4 in the case of He^6. The atomic weight, A is the sum of the number of protons and neutrons

of the oxygen atom) is equal to 931 Mev, where Mev stands for millions of electron volts. Since the atomic weight of the proton is 1.0076, it is obvious that in terms of energy, the proton is the equivalent of 931 × 1.0076 or 937 Mev. If we represent the mass unit by E_o in order to get the equivalent of their energy. Thus, $E = E_o A$ and vice versa. A definite amount of energy E corresponds to the atomic weight $A = \frac{1}{E_o} E$.

If then in a nuclear process the final products compared with the initial products undergo what is called *packing* or a loss of mass, it will be necessary in fulfillment of the law of the conservation of energy that in place of the mass deficit $\triangle A$ a certain amount of energy $\triangle E = E_o A$ is liberated. And it is this *atomic energy* which in so far as it emerges in the form

Fig. 3 The isotopes of Lithium, Li^6, Li^7, and Li^8

of heat that we are interested in. At least with regard to uranium (and also thorium) the process of producing atomic energy by *fission* could be developed to a controllable chain reaction which some day may be converted into useful power by means of turbo-generators.

ATOMIC ENERGY BY NUCLEAR FISSION

Of the numerous nuclear reactions subsequent to the first man-induced transmutation of an element by E. Rutherford in 1919, two experiments are of especial importance. The first of these was the experiment of J. D.

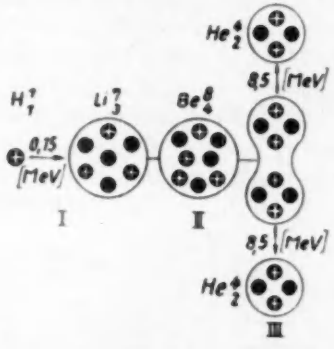


Fig. 4 Initial state I, intermediate state II, and final state III, of the Cockroft-Walton experiment

Cockroft and E. T. Walton in 1932 in which the following reaction took place:

$$H_1^1 + Li_3^7 + E_1 \rightarrow (Be_4^8) \begin{cases} He_2^4 \\ He_2^4 \end{cases} + E_2$$

In this reaction, a proton H_1^1 of kinetic energy $E_1 = 0.15$ Mev is used for bombarding a nucleus of Lithium Li_7^3 resulting in the unstable compound nucleus of beryllium Be_4^8. This immediately splits into two helium nuclei with a total kinetic energy $E_2 = 17.1$ Mev evenly divided between each of the two particles.

This result can easily be checked by the relativity equation already mentioned. Written in shorthand manner, $H_1 + Li_3 + E_1 \rightarrow 2\ He_2 + E_2$ yields, in the difference between the amount of delivered energy E_2 and the amount of introduced energy E_1, the amount of gained energy $\triangle E = E_2 - E_1$.

The energy E_2 however, originates as by the equation $H_1 + Li_3 \rightarrow 2\ He_2 + \triangle A$ from the mass defect $\triangle A = (H_1 + Li_3) - (2\ He_2)$ suffered by the final products as compared with the initial products of the nuclear reaction. And, owing to the general relation $\triangle E = E_o\ \triangle A$ already derived, one finds as energy $E_2 = E_o\ [(H_1 + Li_3) - (2\ He_2)]$ so that the pure energy output $\triangle E = E_2 - E_1$ or the energy output $\triangle E = E_o\ (H_1 + Li_3 - 2\ He_2) - E_1$, or, inserting the value $E_o = 931$ Mev and the values of the Table, the output $\triangle E + 931\ (1.0081 + 1.0018 - 2 \times 4.0039) - 0.15$ or, the output $E = 17$ Mev which is, indeed the value given above.

This represents an enormous gain in energy but in its practical application its efficiency is very low because in such bombardment experiments only an extremely small percentages of the total number of bombarding particles actually hit lithium nuclei. Most of the protons pass between the enormous (relatively) spaces between the nuclei where they collide with the shell electrons and in this way lose their energy by ionizing the atoms of lithium.

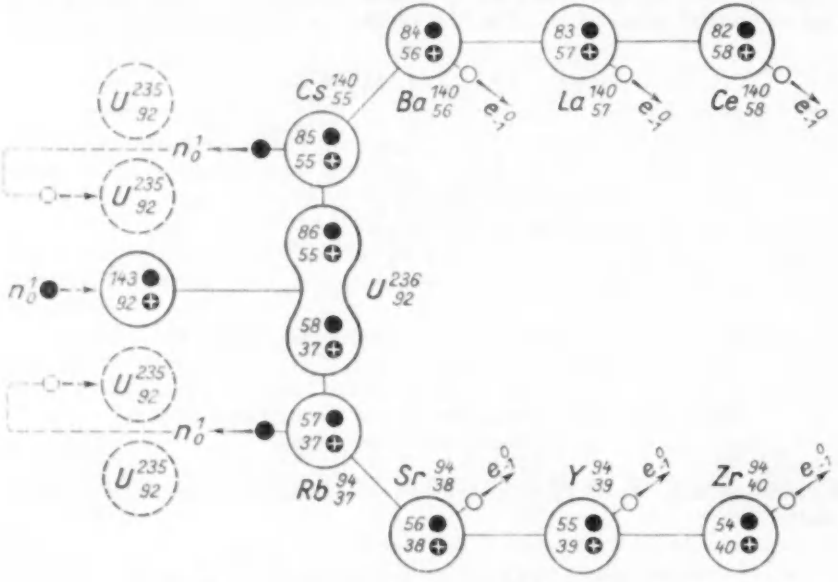


Fig. 5 The unmoderated chain reaction leading to the explosion of a mass of uranium-235

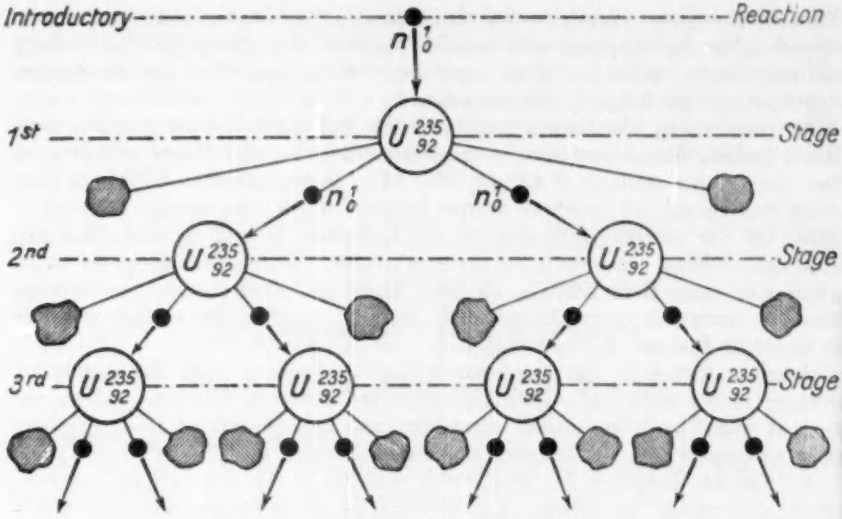


Fig. 6 Schematic diagram illustrating the principle of the nuclear fission of uranium-235

Far too many protons have to be accelerated in order that one among them succeeds in hitting a lithium nucleus for the process to be effective in the production of energy.

The low efficiency of the hydrogen-lithium reaction does not, however, affect its importance in nuclear investigation, and as will be shown later, under different conditions, this reaction may still have great practical application.

The second of the two important experiments referred to above was the experiment performed by O. Hahn in 1939 involving the fission of the uranium isotope U_{92}^{235} when bombarded by neutrons. In this process, the uranium 92 nucleus captures a neutron forming the unstable compound nucleus U_{92}^{236}. This, then, bursts into two fragments of more or less medium atomic weight, which subsequently undergo further transmutation. Also, in the process of *fission* as this is called, two or more neutrons are emitted. The reaction is as follows:

$$n_o + U_{92}^{235} \rightarrow (U_{92}^{236}) \begin{cases} Cs_{55}^{140} + n_o \\ Rb_{37}^{94} + n_o \end{cases}$$

releasing the energy E = 200 Mev. (See Fig. 5)

Three years after the significance of Hahn's experiments had swept around the scientific world, on December 2nd, 1942, under the direction of E. Fermi, it became possible in the first atomic *pile*, to lead back the neutrons emitted in the process of fission so as to produce a self sustaining chain reaction. When an initial fission took place the extra neutrons so released brought about fission in other uranium atoms, and the process so started continued until countless billions of the nuclei released their vast store of energy. And, again, three years after that, on August 5, 1945, the atomic bomb had been finished and tested, and exploded over the city of

Hiroshima. Since that time the chain reaction of uranium has undergone considerable development and while much of the effort has been along military lines, work has also been done with the object of developing neuclear energy for peaceful purposes.

In considering these two reactions, the hydrogen-lithium reaction and the uranium fission reaction, it might appear that the latter releases, by far, the greater amount of energy, 200 Mev as compared to 17 Mev. One must not be misled by these values because when, the energy released is based on the respective masses of the elements, it will be seen that the hydrogen-lithium reaction is far more powerful. Uranium is about 34 times greater in mass than lithium, so that, based on equal masses, the lithium reaction energy is approximately 2.5 times as great as the energy released in uranium fission.

Another factor in the hydrogen-lithium reaction is that the supply of lithium in the world is practically unlimited whereas, uranium, while not rare, is found only in limited quantities, and can be refined to a sufficient state of purity only by complex and expensive methods.

At present, however, no way seems possible to use the lithium reaction under controlled conditions, as is the case in the uranium pile. To effect a chain reaction in the case of lithium, it would be necessary to establish a

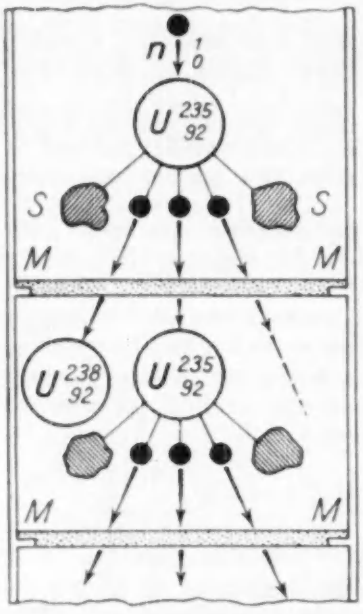


Fig. 7 The moderated chain reaction in a uranium pile charged with natural uranium of isotopes U-238, U-235, and U-234. It is assumed that in the process of fission three additional neutrons are created of which one is lost by diffusion through the walls of the pile or by absorption within the pile. The secon neutron combines with the isotope U-238 leading, according to the equation

$$U_{92}^{238} + n_{0}^{1} \longrightarrow U_{92}^{239} \longrightarrow Np_{93}^{239} + e_{-1}^{0} \longrightarrow Pu_{94}^{239} + e_{-1}^{0}$$

to the production of plutonium. The third neutron effects the fission of other U-235 nuclei

kindling temperature of some 10 million degrees. At that temperature, the thermal velocity of the protons in a mass of lithium and hydrogen, would be sufficient to bring about the reaction, under suitable conditions. It should be evident that even if such an initial kindling temperature could be established and the lithium reaction started, ordinary materials would instantly vaporize at such temperatures and the reaction would proceed with explosive violence.

NOTE: This is the first of two articles by Dr. Wessel. A second, dealing with the production of atomic energy by nuclear fission and nuclear synthesis will be available on request.

Atomic Fissions

News From The Atomic World

Radiological Health Course

The School of Public Health, University of Michigan at Ann Arbor, has announced a Course in Radiological Health on February 5-8, 1951. Given at the request of the Michigan Health Officers Association, the course is planned to serve all public health personnel. This course is NOT a course in civilian defense, however. It is designed to provide public health workers with information that should aid them in more readily understanding some of the problems in which they might sometime receive defense training.

Registration for the course begins at 8:00 a.m., Monday, February 5, and will open at 9:00 a.m. with introductory remarks by Henry F. Vaughan, Dean of the School of Public Health.

Application for enrollment in the course should be submitted in writing by letter addressed to H. E. Miller, School of Public Health, University of Michigan, Ann Arbor, Michigan. Applicans will be enrolled to the extent of seating space available. It is suggested therefore that persons planning to attend make early application. The enrollment fee is $5.00.

There are a limited number of rooms available (most of them doubles) at the Michigan Union. Persons wishing rooming accomodations should make application early and direct to the University of Michigan Union. Make sure to state that the accomodation is requested in connection with attendance of this course.

New AEC Production Site in South Carolina

The United States Atomic Energy Commission on November 28 announced that its new production plants to be designed, built and operated by the E. I. du Pont de Nemours Company of Wilmington, Delaware, will be located in Aiken and Barnwell counties, South Carolina near the Savannah River. About 250,000 acres will be acquired for the site. Exact boundaries remain to be determined. The new site will be known as the Savannah River Plant.

As was noted by the President last July in asking the Congress to appropriate $260,000,000 to start construction, these additional plants, like the existing facilities, will provide materials which can be used either for weapons or for fuels potentially useful for power purposes.

The Commission emphasized, however, that the operations at the Savan-

nah River plants will not involve the manufacture of atomic weapons.

The site was chosen by the Commission after a four-month study of more than 100 sites by the du Pont Company and AEC engineers with the assistance of other federal agencies.

First Non-AEC Nuclear Reactor

The first non-AEC owned and operated nuclear reactor in the United States will be built by the Consolidated University of North Carolina, using nuclear fuel loaned by the Atomic Energy Commission.

The proposed reactor, which will provide facilities for nuclear engineering research and education, will be located on the campus of the North Carolina State College, Raleigh, North Carolina. Present design calls for a low-power reactor having a maximum power level of 10 kilowatts, which will use enriched fuel containing not over one kilogram (2.2 pounds) of fissionable uranium 235.

The reactor will be housed in a special laboratory building to be erected with a fund of $200,000 that has been provided by the Burlington Mills Foundation.

Actual transfer of fissionable material required for the reactor will take place after final approval by the Atomic Energy Commission of the safety and security provisions in the completed reactor itself and the plan for its operation.

The North Carolina reactor will be a "water boiler" type reactor, similar to one that has been in operation at the Los Alamos Scientific Laboratory since 1944. The significant feature of the water boiler design is that the uranium fuel is a solution of uranium salt in water.. Such reactors are also called homogeneous reactors as contrasted to reactors in which metallic uranium fuel elements are used. At Los Alamos the Water Boiler has proved of great value for general research purposes.

In announcing approval of the North Carolina reactor, AEC Chairman Gordon Dean said, "The Commission feels that the University is to be congratulated on having the foresight and initiative to make available on its own responsibility funds and technical talent to further the broad development of atomic energy in the United States.

In view of the inherent controls on this type of reactor and the low power level at which it will beoperated, the AEC's Reactor Safeguard Committee concluded that the proposed reactor can be operated safely on a university campus, provided a satisfactory plan of operation is established.

The plutonium production of the proposed reactor will total less than a gram a year, an insignificant production rate in the manufacture of atomic weapons. In view of this fact and since the reactor will be useful in the conduct of research and training, the private construction, operation and ownership of the reactor is permissible under the Atomic Energy Act.

The cost of the reactor, exclusive of the uranium fuel to which AEC will retain title is estimated at $100,000, which will be provided by the College. Some 60 undergraduate and graduate students in nuclear engineering are enrolled at the College this semester.

New Books on Atomics

Pocket Encyclopedia of Atomic Enery edited by Frank Gaynor; first edition; 5¾ by 8½ in.; 204 pages; cloth; published by the Philosophical Library, 15 E. 40th Street, New York, N. Y.; 1950. Price $7.50.

The purpose of this book is to present a comprehensive collection of brief explanations and definitions of concepts and terms in the field of Nuclear Physics and Atomic Energy. It is aimed at the scholar, researcher, teacher, librarian, student and intelligent layman. This book is not a textbook. As the author points out in the preface, it is merely a sort of tourist's guide in the new and strange realm of the atom. It is not an accurate detail map of this strange land, not meant to describe every hill and vale. It is intended to furnish the stranger on a brief excursion into this unknown land with a general bird's eye view, merely to point out to him the most outstanding landmarks and the main highways which will lead him to his goal—that is, to a general understanding of the atom, its nucleus, its energy, and relationship to human life and progress.

There are individual entries for every element indicating chemical symbol, group of the periodic table, name of discoverer, date of discovery, atomic number, atomic weight, melting point, boiling point, specific gravity, stable isotopes, radio isotopes. Brief descriptions of the best known types of nuclear reactions are given. There is also an entry for every member of the known radioactive family. Furthermore, there are a great many brief and concise descriptions of subjects such as nuclear fission, tracer technique, atomic bombs, the H-bomb, etc. Finally, thumbnail biographical sketches of outstanding nuclear physicists and chemists give the reader a familiarity with the personalities involved with the field of nuclear science.

Nuclear Physics by Francis Bitter. First Edition; 6 by 9 in.; 224 pages; illustrated; cloth; published by the Addison-Wesley Press, Inc., Kendall Square Bldg., Cambridge 42, Mass.; 1950. Price $5.50.

This new book has been written to give the non-specialist a clear understanding of the basic concepts and processes of the rapidly developing field of nuclear physics. The author assumes only a minimum background of technical knowledge on the part of the reader.

Engineers, biological scientists and educated laymen, will find in this book a clear exposition of this new fascinating field which is assuming more importance every day in their own work.

Where does nuclear energy come from? Why is nuclear energy completely different from the energy of chemical reactions? These and many other questions are discussed in detail. The presentation has been kept as simple as possible to make it easy for the reader to follow the main thread of the discussion. An up-to-date isotope chart is included at the end of the book. Some of the problems and exercises at the ends of the chapters have been chosen with the intention of interesting students who may wish to think somewhat more deeply about matters discussed in the text. An idea of the contents of the book may be had from the following chapter headings: 1—The Evolution of Nuclear Physics; 2—Definitions and Prerequisites; 3—Protons, Electrons, and Quanta; 4—Neutrons, Neutrinos and Nuclei; 5—Rays and Beams; 6—Masses and Moments; 7—Radioactivity; 8—Nuclear Reactions; 9—The Consequences of Fission. This is a splendid book for anyone interested in an aspect of nuclear physics.

Au Revoir

This issue of ATOMICS is the last to be published.

There are excellent publications covering the scientific phases of nuclear physics and atomic energy. Our purpose in publishing ATOMICS was to interpret this scientific information in practical engineering terms for engineers and technicians who have a need to understand atomic developments. In other words, to broaden the understanding of practical uses of atomic energy among people who don't have a scientist's background.

Those of you who have been reading ATOMICS have been enthusiastic in your reception of the job Mr. Kramer has done. A publication, however, must serve a field of interest large enough to support the costs of publishing and judged by our experience to date there aren't enough individuals with a sustained interest in atomic applications to justify such a magazine.

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